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(54) Acoustic signal reproducing apparatus.

(57) An acoustic signal reproducing apparatus for reproducing acoustic signals by headphone devices (2) is disclosed. The left channel and right channel acoustic signals are provided by a device (23) for processing the acoustic signals with constant transmission characteristics from an imaginary sound source to both of the listener's ears. The left channel and right channel acoustic signals, processed in this manner by the device (23), are provided by an acoustic signal processing device (21) with a level difference and time difference consistent with changes in orientation of the listener's head (M).

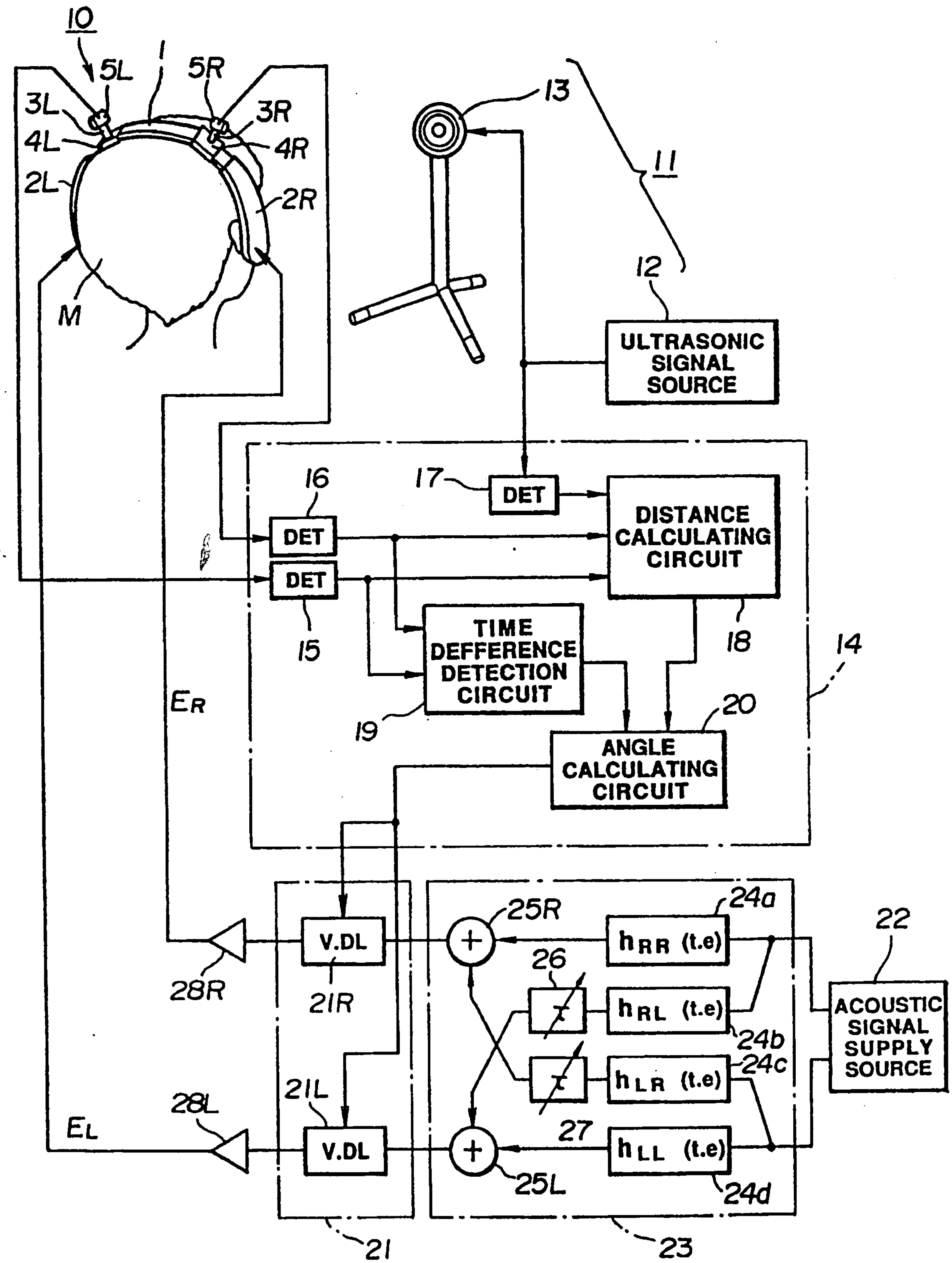
10
1
5L
5R
3L
3R
4L
4R
2L
2R
M
13
11
12
ULTRASONIC SIGNAL SOURCE
14
16
17
DET
DET
DET
DISTANCE CALCULATING CIRCUIT
15
18
TIME DEFFERENCE DETECTION CIRCUIT
19
20
ANGLE CALCULATING CIRCUIT
ER
EL
V.DL
V.DL
21R
21L
28R
28L
25R
25L
24a
24b
24c
24d
26
27
h_{RR} (t.e)
h_{RL} (t.e)
h_{LR} (t.e)
h_{LL} (t.e)
τ
τ
22
ACOUSTIC SIGNAL SUPPLY SOURCE
21
23

FIG.1

ACOUSTIC SIGNAL REPRODUCING APPARATUS

This invention relates to acoustic signal reproducing apparatus including a headphone device.

In reproducing acoustic signals using a pair of headphone units worn on the listener's head in the vicinity of the listener's ears, there is known a binaural system for optimising the sense of the direction of a sound image, or the sense of the sound source lying at some fixed position outside the listener's head.

With such a binaural acoustic signal reproducing system, as disclosed for example in Japanese patent kokoku specification 283/53, the acoustic signals reproduced by the headphone device are subjected in advance to a predetermined signal processing. The sense of the direction of the sound image, or the sense of the sound source lying at some fixed position outside the listener's head, is governed by the difference in sound volume, and in the phase of the sounds heard by the left and right ears.

By the above-mentioned signal processing is meant processing such that when the acoustic sound is to be reproduced by the speaker units, an acoustic effect equivalent to that produced by the difference in distance from the sound source, that is, the speaker units, placed at some distance from the listener, to the listener's left and right ears, or the reflection or diffraction in the vicinity of the listener's head, is produced in the acoustic output reproduced by the headphone device. Such signal processing may be realised by subjecting the acoustic signals for the listener's left and right ears to, for example, convolutional integration of the impulse response corresponding to the above-mentioned acoustic effects.

However, when the acoustic sound is to be reproduced by speaker units placed at a distance from the listener, the absolute position of the sound image is not changed even if the listener moves his or her body or head, so that the relative direction or position of the sound image sensed by the listener is changed. Conversely, when the acoustic sound is reproduced in accordance with the binaural system, using the headphone device, the headphone device moves with movement of the listener's head, so that the relative direction and position of the sound image as sensed by the listener remains unchanged.

In this manner, when the acoustic sound is reproduced by the binaural system, using the headphone device, the sound field may be formed within the listener's head, because of the difference in the shift of the sound image with respect to change in the orientation of the listener's head, with the result that it is difficult to fix the sound image at a position ahead of the listener. In addition, the sound image lying ahead of the listener tends to be moved upwards.

There has also been proposed an acoustic signal reproducing system in which, as described in Japanese patent kokai specification 227/42 or Japanese patent kokoku specification 19242/54, the changes caused in the orientation of the listener's head are sensed, and the signal processing is changed on the basis of the sensed results, so as to provide an optimum forward fixed sound source orientation relative to the headphone device. With this type of acoustic signal reproducing system, a direction sensor, such as a gyro-compass or magnetic needle, is positioned on the listener's head. A level adjustment circuit and a delay circuit for processing the acoustic signals, are controlled by the output of the direction sensor to provide an ambience of the sound field similar to that provided by sound reproduction by loudspeaker units placed at some distance from the listener.

With the above-described binaural acoustic reproducing system, in which a gyro-compass or other direction sensor is provided in the headphone device, signal processing dependent upon the changes in the direction of the listener's head may be controlled to provide a satisfactory fixed sound image orientation feeling.

However, for controlling the signal processing in dependence upon changes in the listener's head position, it is necessary to measure in advance the impulse response, that is the transmission characteristics, corresponding to the acoustic effects applied to acoustic signals for the left and right ears, for each of predetermined angles, to store a substantial amount of transfer characteristic data in storage means, and to read out the data responsive to occasional changes in the listener's head position, for performing the necessary real-time convolutional integration of the acoustic signals. A processing apparatus with a large processing capacity and a high processing speed is therefore required.

According to the present invention there is provided an acoustic signal reproducing apparatus comprising :

a reference signal source for transmitting a reference signal for detecting the position of a listener's head ;

a pair of signal detection means arranged at two positions on the listener's head for receiving the reference signal transmitted by said reference signal source ;

calculating means for calculating changes in orientation of the listener's head relative to an imaginary sound source on the basis of output signals from said pair of signal detection means ;

transmission characteristic processing means for providing the left channel and the right channel of the input acoustic signals with predetermined transmission characteristics from said imaginary

sound source to both of the listener's ears ; and acoustic signal processing means for providing the right and left channel acoustic signals from said transmission characteristic processing means with a level difference and a time difference consistent with the change in orientation information from said calculating means ;
the acoustic signals being reproduced by headphone devices by means of said acoustic signal processing means.

Thus, in accordance with the present invention, there is provided an acoustic signal reproducing apparatus comprising means for detecting the rotational angular position of the listener's head, means for calculating changes in the orientation of the listener's head relative to an imaginary sound source on the basis of output signals from said detection means, transmission characteristic processing means for providing left channel and right channel acoustic signals with constant transmission characteristics from said virtual sound source to both ears of the listener, and acoustic signal processing means for providing the left channel and right channel acoustic signals processed by the transmission characteristic processing means with a level difference and a time difference consistent with changes in the direction of the listener's head as determined by said calculating means, the acoustic signals processed by the acoustic signal processing means being reproduced by a headphone device.

With such an acoustic signal reproducing apparatus, since constant transmission characteristics between the imaginary sound source and the listener's ears are afforded by transfer characteristic processing means to the left channel and right channel acoustic signals, the acoustic signals of both channels can be provided with the necessary transmission characteristics by means of a simplified calculating device, without the necessity of variably controlling the coefficients of the transmission characteristic processing means on a real time basis. In addition, the acoustic signals of the respective channels processed by the transmission characteristic processing means are provided by the acoustic signal processing means with a level difference and a time difference consistent with the changes in the orientation of the listener's head as determined by the calculating device, and the acoustic signals thus processed by the acoustic signal processing means are supplied to the headphone device. In this manner satisfactory binaural reproduction may be achieved with a highly natural fixed sound image orientation sense, without the position of the imaginary sound source being moved with the listener's bodily movements.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which :

Figure 1 is a schematic and block diagram of an embodiment of acoustic signal reproducing apparatus according to the present invention ;

Figure 2 shows time charts for the apparatus of Figure 1 ;

Figure 3 is a diagrammatic view illustrating a distance and an angle calculated by the apparatus of Figure 1 ;

Figures 4(A), 4(B) and 4(C) are plan views showing the relative positions between an imaginary sound source and a listener ; and

Figure 5 is a block diagram showing an acoustic signal processing circuit for one of the channels in the apparatus of Figure 1.

Referring first to Figure 1, an acoustic signal reproducing apparatus according to the present invention includes a headphone device 10 comprising a head-band 1 for the listener's head and supporting a pair of headphone units 2L, 2R in the vicinity of the listener's left and right auricles.

Two sliders 4L, 4R carrying upstanding supporting arms 3L, 3R are slidably mounted on the head-band 1, and a pair of signal sensors 5L, 5R for sensing position-detecting reference signals from a reference signal source 11 are mounted on the distal ends of the supporting arms 3L, 3R which are mounted upright on sliders 4L, 4R in turn slidably mounted on the head-band 1, so as to be supported at a distance from the head-band 1.

The reference signal source 11 comprises an ultrasonic signal source 12 and an ultrasonic loudspeaker 13 transmitting the ultrasonic signals from the source 12 as the reference signals. The signal sensors 5L, 5R for sensing the reference signals are each formed by ultrasonic microphones.

The ultrasonic signals, that is the position-detecting reference signals transmitted from the ultrasonic loudspeaker 13, shown at A in Figure 2, are phase detectable ultrasonic waves, such as a burst of ultrasonic wave having a predetermined level and transmitted intermittently at a predetermined period, or so-called level-modulated waves exhibiting level fluctuation at a predetermined period.

The signal sensors 5L, 5R, provided on the headphone device 10, are responsive to the position-sensing ultrasonic reference signals from the ultrasonic loudspeaker 13 to supply detection signals, shown at B and C in Figure 2, respectively, having relative time lags consistent with the relative position between the listener and the ultrasonic loudspeaker 13.

The signal sensors 5L, 5R are supported by the supporting arms 3L, 3R at positions spaced apart from the head-band 1 and the headphone units 2L, 2R of the main headphone body when it is worn on the listener's head M. Thus the signal sensors 5L, 5R are not hidden by the listener's head M when the listener moves his or head or body, so that the ultrasonic

waves transmitted from the ultrasonic loudspeaker 13 can be sensed satisfactorily and the position-sensing reference signals detected stably and accurately. The signal sensors 5L, 5R may be adjusted to an optimum position for detecting the position-sensing reference signal by sliding the sliders 4L, 4R along the headband 1. Since the position of the headphone units 2L, 2R depends on the shape and the size of the listener's head M, and hence differs from person to person, the positions of the signal sensors 5L, 5R need to be adjusted in association with the position of the headphone units 2L, 2R.

The detection signals produced from the signal sensors 5L, 5R, are transmitted to a calculating unit 14, which includes first and second edge detection circuits 15 and 16, supplied with detection signals by the signal sensors 5L, 5R of the position-sensing reference signals, respectively, and a third edge detection circuit 17, supplied with the ultrasonic signals from the ultrasonic signal source 12, that is the position-sensing reference signals.

The first and second edge detection circuits 15 and 16 detect the rising edges of the detection signals from the signal sensors 5L, 5R, respectively, for supplying pulse signals associated with the rising edges, as shown at D and E in Figure 2. The pulse signals from the first and second edge detection circuits 15 and 16 are supplied to a distance calculating circuit 18 and a time difference detection circuit 19. The third edge detection circuit 17 detects the rising edges of the ultrasonic signals from the ultrasonic signal source 12 to supply pulse signals, shown at F in Figure 2, associated with the rising edges. The pulse signals produced by the third edge detection circuit 17 are supplied to the distance calculating circuit 18.

The distance calculating circuit 18 detects a time difference t_1, shown at ΔT_1, in Figure 2, between the pulse signal obtained by the third edge detection circuit 17 and the pulse signal obtained by the first edge detection circuit 15, and a time difference t_2, shown at ΔT_2 in Figure 2, between the pulse signal obtained by the third edge detection circuit 17 and the pulse signal obtained by the second edge detection circuit 16. The calculating circuit 18 then calculates, on the basis of the time difference t_1 and t_2 and the sound velocity V, the distance l_0, shown by an arrow in Figure 3, between the ultrasonic loudspeaker 13 and the centre of the listener's head M.

The sound velocity V_0 may be preset as a constant in the distance calculating circuit 18, or changed as a function of changes in temperature, humidity or atmospheric pressure. The calculated distance l_0 may be compensated on the basis of the relative positions of the signal sensors 5L, 5R with respect to the centre of the listener's head M or its shape and/or size.

The signals for the distance l_0 and the time difference t_1 and t_2 are transmitted to an angle calculating circuit 20.

The time difference detection circuit 19 detects a time difference t_3, shown by ΔT_3 in Figure 2, between the pulse signal from the first edge detection circuit 15 and the pulse signal from the second edge detection circuit 16. The signal for the time difference t_3 is supplied to the angle calculating circuit 20.

The angle calculating circuit 20 calculates, from the time differences t_1, t_2 and t_3, the distance l_0, the sound velocity V and the radius r of the listener's head M, an angle θ_0, shown by an arrow in Figure 3, indicating the orientation of the listener's head M. The angle θ_0 may be found by, for example, the following formula :

$$\theta_0 \fallingdotseq \sin^{-1}\{V^2(t_1 + t_2)t_3/4rl\} \quad (1)$$

and, with the position of the ultrasonic speaker 13 as the reference position of the imaginary sound source, the rotational angle θ of the listener's head M with respect to a desired imaginary sound source and the relative distance 1 of the listener's head M from the imaginary sound source are calculated to find an angular position which takes into the directivity of the desired imaginary sound source.

The angular position information, produced by the angle calculating circuit 20, is supplied to an acoustic signal processing circuit 21.

Left channel and right channel acoustic signals S_L, S_R, from an acoustic signal supply source 22, are supplied to the acoustic signal processing circuit 21 by means of a transmission characteristic processing circuit 23.

The acoustic signal supply source 22 is a unit for supplying predetermined left channel and right channel acoustic signals S_L, S_R, and may for example be one of a variety of disc recording/reproducing apparatus, a tape recording/reproducing apparatus, or a radio receiver.

The transmission characteristic processing circuit 23 is a circuit for performing a predetermined signal processing operation for providing the left and right channel acoustic signals S_L, S_R from the acoustic signal supply source 22 with predetermined transmission characteristics from the imaginary sound source to both of the listener's ears, and includes first to fourth signal processing circuits 24a, 24b, 24c and 24d having preset coefficients providing the above-mentioned transmission characteristics. In each of the signal processing circuits 24a to 24d, an impulse response indicative of transmission characteristics to each ear of the listener in reproducing the left and right channel acoustic signals S_L and S_R is set, with a pair of loudspeaker units for the left and right channels, installed opposite to the listener and at some distance from each other as an imaginary or virtual sound source, on the basis of the above-mentioned transmission characteristic information.

Thus the first signal processing circuit 24a sets an impulse response $\{h_{RP}(t, \theta)\}$ indicative of transmission characteristics to the right ear of the sound repro-

duced from the right channel acoustic signal S_R. The second signal processing circuit 24b sets an impulse response $\{h_{RL}(t, \theta)\}$ indicative of transmission characteristics to the left ear of the sound reproduced from the right channel acoustic signal S_R. The third signal processing circuit 24c sets an impulse response $\{h_{RL}(t, \theta)\}$ indicative of transmission characteristics to the right ear of the sound reproduced from the left channel acoustic signal S_L. Finally, the fourth signal processing circuit 24d sets an impulse response $\{h_{LL}(t, \theta)\}$ indicative of transmission characteristics to the left ear of the sound reproduced from the left channel acoustic signal S_L.

These impulse responses may be previously set in association with transmission characteristics, taking the directivity or the like features of the imaginary sound source into account, and stored in a memory, such as ROM, so as to be subsequently read out on the basis of the read-out address determined from the distance 1 and the angle θ.

In the transmission characteristic processing circuit 23, the right channel acoustic signal S_R is transmitted to the first and second signal processing circuits 24a and 24b. In the first signal processing circuit 24a, the right channel acoustic signal S_R is subjected to signal processing by convolutional integration of the impulse response $\{h_{RR}(t, \theta)\}$. In the second signal processing circuit 24b, the right channel acoustic signal S_R is subjected to signal processing by convolutional integration of the impulse response $\{h_{RL}(t, \theta)\}$.

The left channel acoustic signal S_L is transmitted to the third and fourth signal processing circuits 24c, 24d. In the third signal processing circuit 24c, the left channel acoustic signal S_L is subjected to signal processing by convolutional integration of the impulse response $\{h_{LR}(t, \theta)\}$. In the fourth signal processing circuit 24d, the left channel acoustic signal S_L is subjected to signal processing by convolutional integration of the impulse response $\{h_{LL}(t, \theta)\}$.

The output signal from the first signal processing circuit 24a is directly supplied to a right-hand adder 25R, while the output signal from the third signal processing circuit 24c is supplied by way of a variable delay circuit 27 to the right-hand adder 25R so as to be added thereat to the output signal from the first signal processing circuit 24a. The output signal from the right-hand adder 25R is supplied to a right-hand signal processing circuit 21R of the signal processing circuit 21. The output signal from the second signal processing circuit 24b is supplied by way of a variable delay circuit 26 to a left-hand adder 25L, while the output signal from the fourth signal processing circuit 24d is directly supplied to the left-hand adder 25L so as to be added thereat to the output signal from the second signal processing circuit 24b. The output signal from the left-hand adder 25L is supplied to a left-hand signal processing circuit 21L of the signal processing circuit 21.

The variable time delay circuits 26 and 27 of the processing circuit 23 provide for variable time difference of the output cross-talk component signals of the second and third signal processing circuits 24b and 24c, and are used for compensating the changes in the time difference of the cross-talk components caused by the difference in head size from person to person.

The left-hand signal processing circuit 21L and the right-hand signal processing circuit 21R of the acoustic signal processing circuit 21 operate responsive to the angular position information derived from the angle calculating circuit 20 to effect variable control of the level and delay characteristics so that the left and right channel acoustic signals S_L, S_R supplied from the acoustic signal supply source 22 by means of the transmission characteristic processing circuit 23 will be provided with the level difference and the time difference consistent with changes in the orientation of the listener's head M.

The output signal from the right-hand signal processing circuit 21R is supplied by means of a right-hand amplifier 28R as a right ear acoustic signal E_R to the right-hand headphone unit 2R for reproduction. Similarly, the output signal from the left-hand signal processing circuit 21L is supplied by means of a left-hand amplifier 28L as a left ear acoustic signal E_L to the left-hand headphone 2L for reproduction.

With this acoustic signal reproducing apparatus, the rotational angle θ of the listener's head M relative to a desired position of an imaginary sound source and a relative distance 1 from the imaginary sound source are calculated by the calculation unit 14 on the basis of the information concerning the above-mentioned angle θ_0 and the distance l_0 indicative of the relative position between the listener's head M and a reference position of the imaginary sound source which is assumed to be the position of the ultrasonic loudspeaker 13, in such a manner that the left and right channel acoustic signals S_L, S_R supplied from the transmission characteristic processing circuit 23 to the headphone units 2L, 2R will be provided with the level difference and the time difference consistent with changes in orientation of the listener's head M relative to the virtual sound source. In this manner, with the above described acoustic signal reproducing apparatus, signal processing for compensating for changes in transmission characteristics caused by movements of the listener's body and head M on a real-time basis is performed by variably controlled the level difference and the time difference in the acoustic signal processing circuit 21, whereby, as may be seen from the relative position between the imaginary sound source and the listener as shown at A, B and C in Figure 4, an optimum sense of the sound source position lying ahead of the listener and outside the listener's head M without shifting of the imaginary sound

source may be obtained in the same way as when the acoustic signals are reproduced by a pair of loudspeaker units SL, SR positioned ahead of the listener P and at some distance from each other.

It will be noted that, in Figure 4 the listener P approaches the loudspeaker units S_L, S_R, that is, the imaginary sound source, as shown at B, from his or her position shown at A, and further turns his head M towards the right-hand loudspeaker unit S_R, as shown at C. With this acoustic signal reproducing apparatus, an optimum sense of the sound source position forwardly and outside the listener's head M, with the imaginary sound source not being moved, may be obtained as a result of signal processing compensating for changes in the transmission characteristics, caused by movement of the listener's head M and body, on a real time basis, thereby providing for binaural reproduction capable of dealing with any of the states shown at A to C in Figure 4.

With this embodiment, the overall level and delay control is performed on the left and right channel acoustic signal S_L and S_R supplied from the transmission characteristic processing circuit 23 to the headphone units 2L, 2R by way of left-hand and right-hand signal processing circuits 21L, 21R. Alternatively, the acoustic signals may be divided by a high-pass filter 41 and a low-pass filter 42, as shown in Figure 5 for one of the left-hand and the right-hand channels, before proceeding to the level and delay control in the manner described above. In this case, the high frequency component signal, obtained by means of the high-pass filter 41, is supplied to a signal adder 45 after having been controlled in signal level by a variable level circuit 43 in accordance with changes in orientation of the listener's head M relative to the imaginary sound source, whereas the low frequency component signal, obtained by means of the low-pass filter 42, is supplied to the signal adder 45 after having been controlled in delay by a variable delay circuit 44 in accordance with the changes in orientation of the listener's head M relative to the imaginary sound source.

Claims

1. An acoustic signal reproducing apparatus comprising :

   a reference signal source (11) for transmitting a reference signal for detecting the position of a listener's bead (M) ;

   a pair of signal detection means (5) arranged at two positions on the listener's head (M) for receiving the reference signal transmitted by said reference signal source (11) ;

   calculating means (14) for calculating changes in orientation of the listener's head (M) relative to an imaginary sound source on the basis of output signals from said pair of signal detection means (5) ;

   transmission characteristic processing means (23) for providing the left channel and the right channel of the input acoustic signals with predetermined transmission characteristics from said imaginary sound source to both of the listener's ears ; and

   acoustic signal processing means (21) for providing the right and left channel acoustic signals from said transmission characteristic processing means (23) with a level difference and a time difference consistent with the change in orientation information from said calculating means (14) ;

   the acoustic signals being reproduced by headphone devices (2) by means of said acoustic signal processing means (21).

2. Apparatus according to claim 1 wherein said reference signal source (11) comprises an ultrasonic signal source (12) and an ultrasonic loudspeaker (13) for transmitting the ultrasonic signal from said ultrasonic signal source (12) as the reference signal, and the pair of signal detection means (5) are ultrasonic microphones (5).

3. Apparatus according to claim 1 wherein said calculating means (14) comprises distance calculating means (18) for calculating the distance between the listener (P) and the reference signal source (11) from the phase difference between said reference signal and the detection signals from said pair of signal detection means (5), and time difference detection means (19) for detecting the time difference between the detection signals from said pair of signal detection means (5), whereby the angular position of the listener's head (M) relative to the imaginary sound source is calculated using the output of said distance calculating means (18) and the output of said time difference detection means (19).

4. Apparatus according to claim 3 wherein said transmission characteristics processing means (22) comprises a first signal processing section (24a) for subjecting the right channel of said input acoustic signals to a convolutional integration of an impulse response indicative of constant transmission characteristics on the right ear of the acoustic signals reproduced from the right channels of the input acoustic signals, a second signal processing section (24b) for subjecting the right channel of said input acoustic signals to a convolutional integration of an impulse response indicative of constant transmission characteristics on the left ear of the acoustic signals reproduced from the right channel of the input acoustic sig-

nals, a third signal processing section (24c) for subjecting the left channel of said input acoustic signals to a convolutional integration of an impulse response indicative of constant transmission characteristics on the right ear of the acoustic signals reproduced from the left channel of the input acoustic signals, a fourth signal processing section (24d) for subjecting the left channel of said input acoustic signals to a convolutional integration of an impulse response indicative of constant transmission characteristics on the left ear of the acoustic signals reproduced from the left channel of the input acoustic signals, first adder means (25R) for adding the output of said first signal processing section to the output of said third signal processing section, and second adder means (25L) for adding the output of said second signal processing section to the output of said fourth signal processing section, wherein the output of said first adder means (24L) is supplied to a headphone unit [illegible] associated with the listener's right ear [illegible] output of said second adder means [illegible] supplied to a headphone unit (2L) associated with the listener's left ear.

5. Apparatus according to claim 4 further comprising a variable delay circuit (26) for delaying the output of said second signal processing means (24b) and a variable delay circuit (22) for delaying the output of said third signal processing means (24c).

6. Apparatus according to claim 1 wherein said acoustic signal processing means (21) variably controls level and delay characteristics of right channel and left channel acoustic signals from said transmission characteristic processing means (23).

7. Apparatus according to claim 6 wherein said acoustic signal processing means (21) comprises, for each of the right channel and left channel acoustic signals from said transmission characteristic processing means (23), a high-pass filter (41) supplied with the output of said transmission characteristic processing means (23), a low-pass filter (42) supplied with the output of said transmission characteristic processing means (23), level control means (43) supplied with the output of said high-pass filter (41), delay control means (44) supplied with the output of said low-pass filter (42), and adder means (45) for adding the output of said level control means (43) to the output of said delay control means (44).

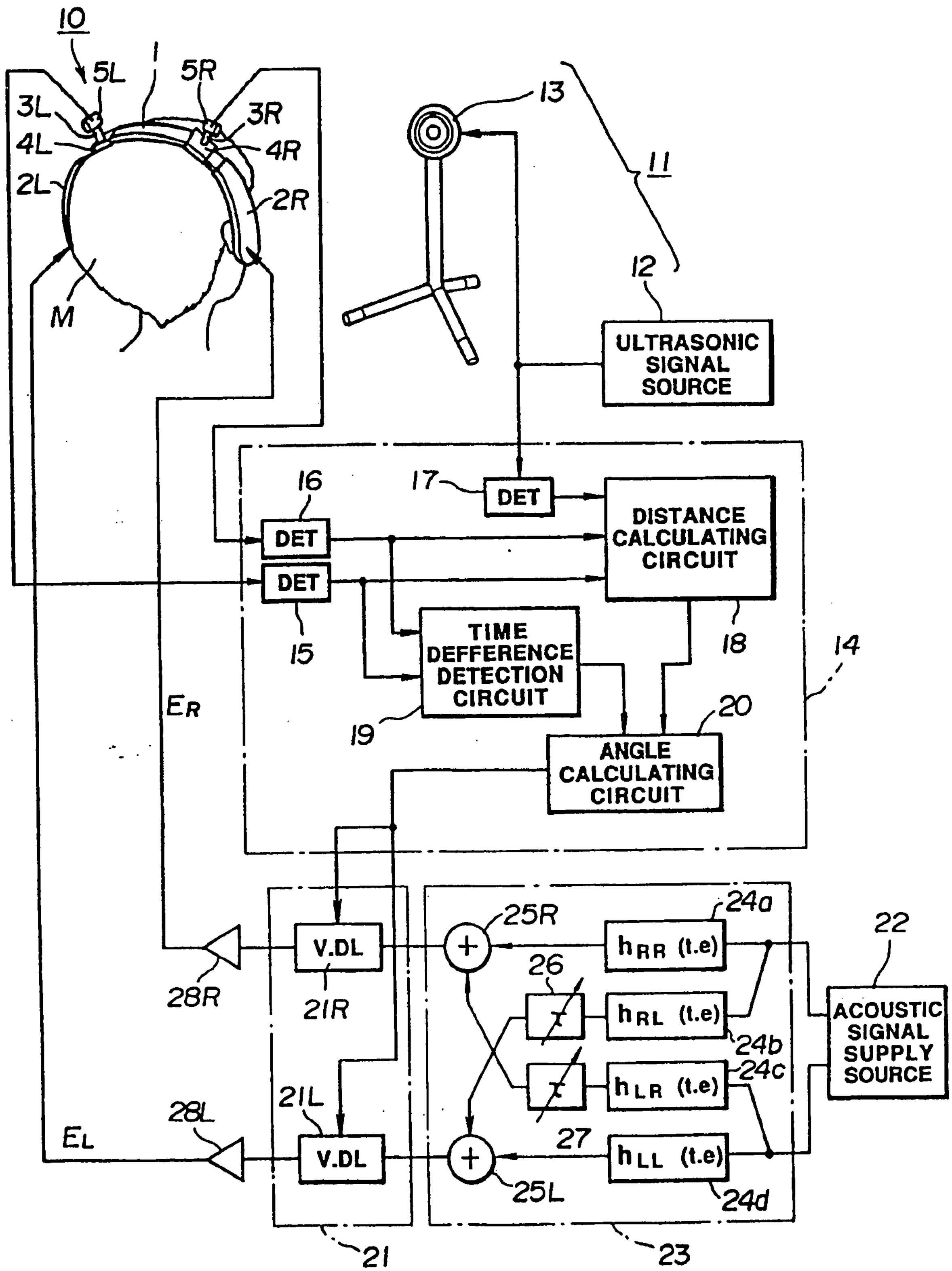
10
5L
1
5R
3L
3R
4L
4R
2L
2R
M
13
11
12
ULTRASONIC SIGNAL SOURCE
16
17
DET
DET
DISTANCE CALCULATING CIRCUIT
DET
15
TIME DEFFERENCE DETECTION CIRCUIT
18
14
ER
19
20
ANGLE CALCULATING CIRCUIT
25R
24a
22
V.DL
hRR (t.e)
28R
21R
26
hRL (t.e)
ACOUSTIC SIGNAL SUPPLY SOURCE
24b
hLR (t.e)
24c
21L
28L
EL
V.DL
27
hLL (t.e)
25L
24d
21
23

FIG.1

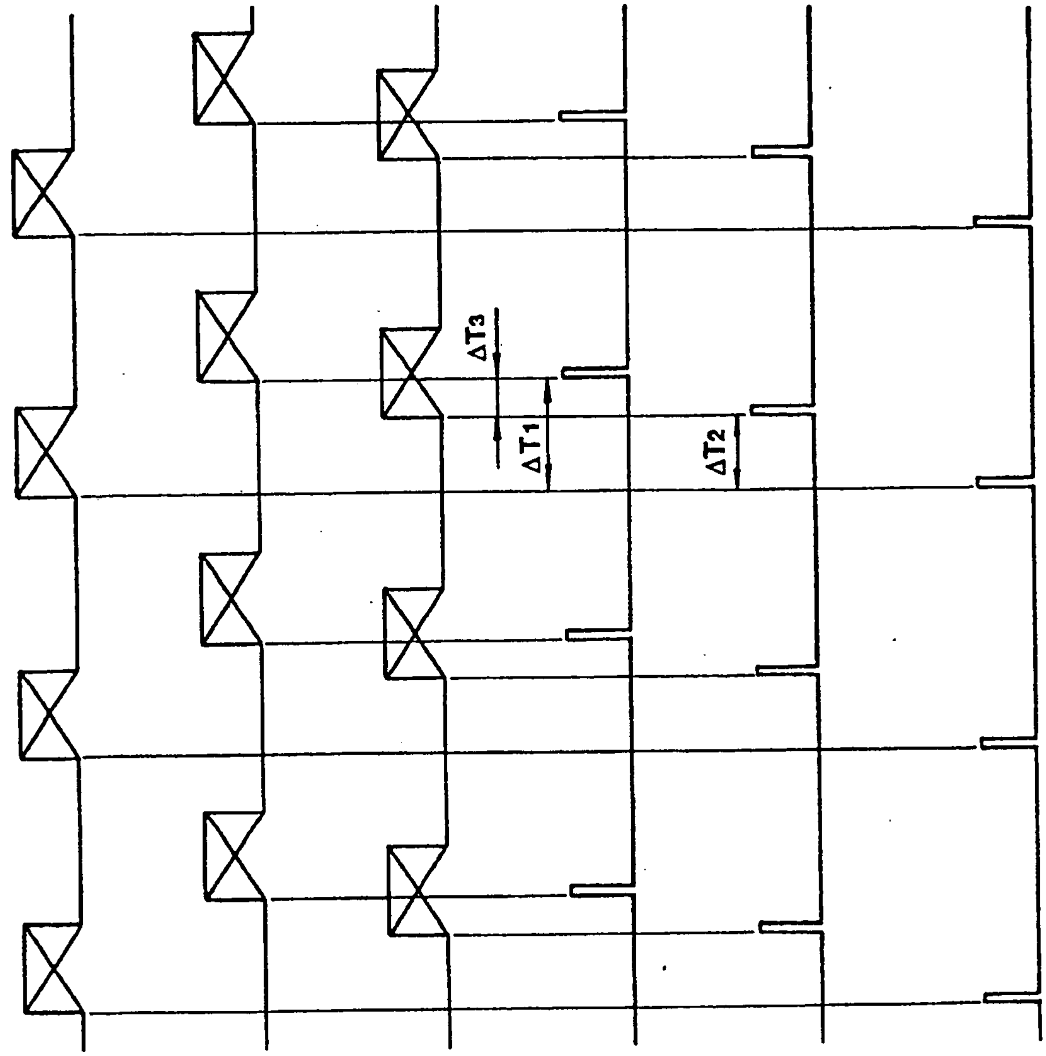

FIG.2(A) POSITION-SENSING REFERENCE SIGNAL

FIG.2(B) OUTPUT OF POSITION SENSOR 5L

FIG.2(C) OUTPUT OF POSITION SENSOR 5R

FIG.2(D) OUTPUT OF FIRST EDGE DETECTION CIRCUIT 15

FIG.2(E) OUTPUT OF SECOND EDGE DETECTION CIRCUIT 16

FIG.2(F) OUTPUT OF THIRD EDGE DETECTION CIRCUIT 17

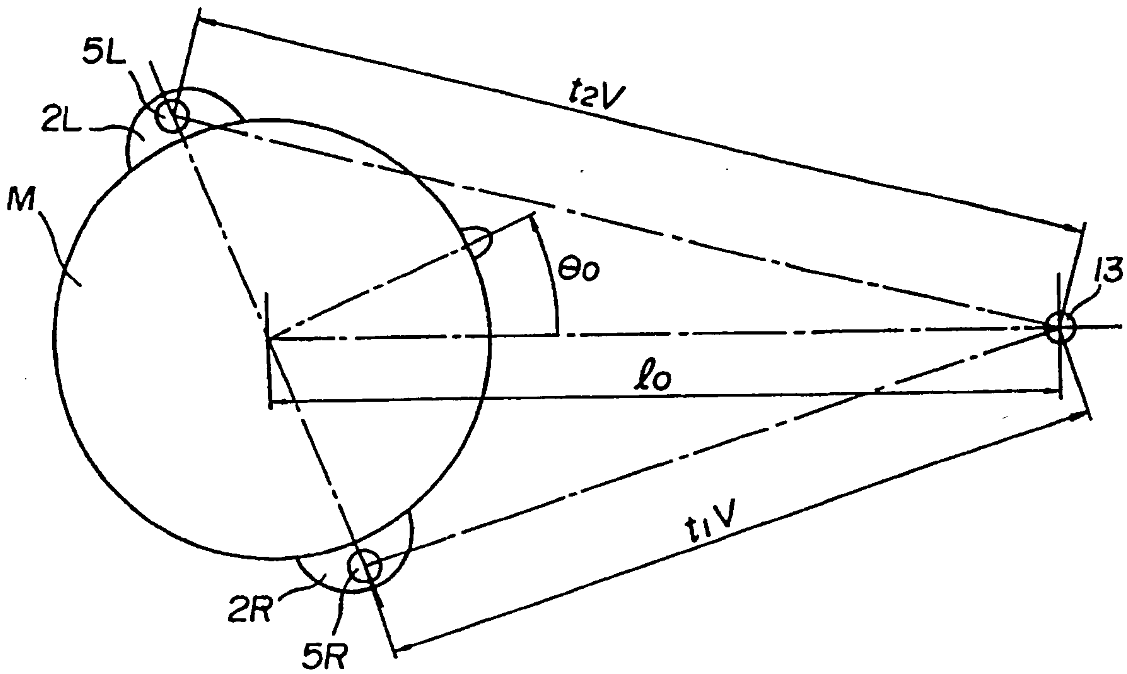

FIG. 3

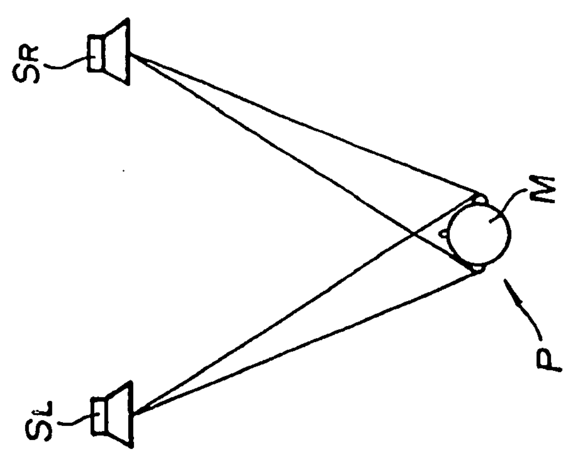

FIG. 4(A)

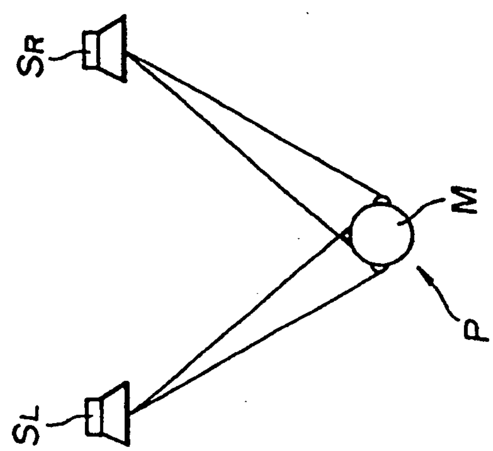

FIG. 4(B)

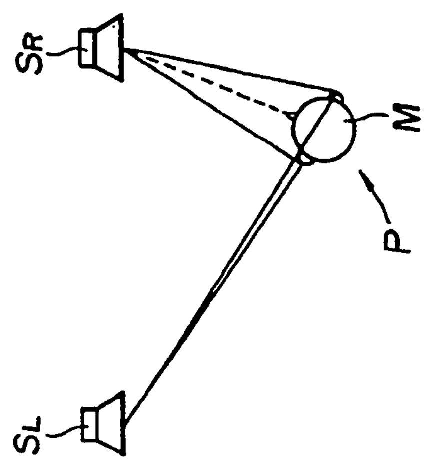

FIG. 4(C)

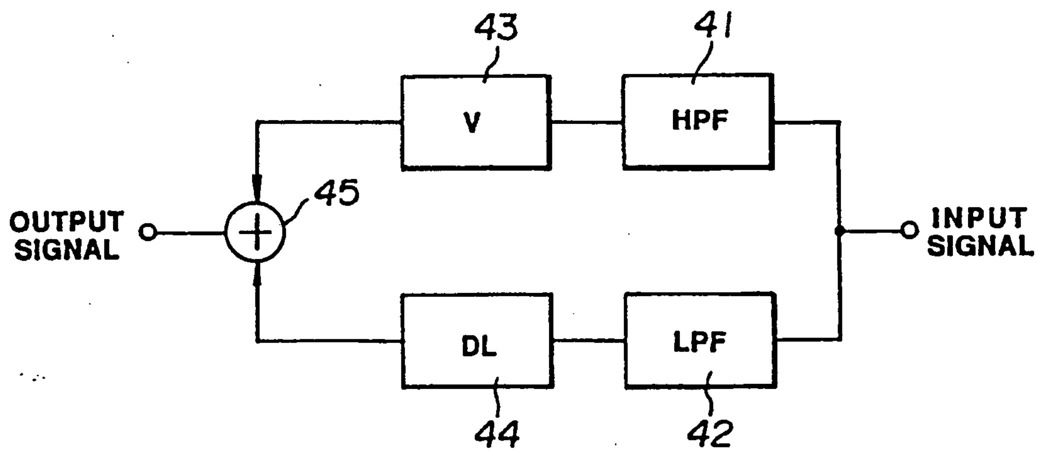

FIG. 5